The technique is particularly effective for vertical conduction devices such as pn and pin diodes, thyristors, heterojunction bipolar transistors, static induction transistors, and vertical field effect transistors. A schematic of some of these devices is shown in Figure 5. Such devices are the foundation of envisioned future optoelectronic, high frequency electronic, and power device technologies.

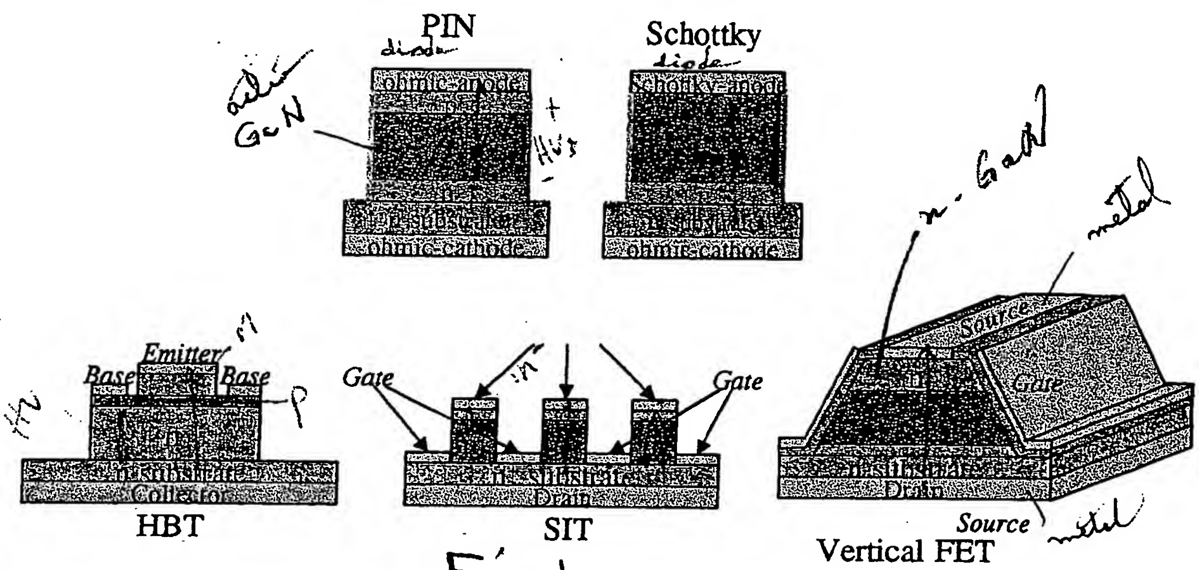


Fig. 1

~~Figure 5. Schematics of vertical conduction devices that may be enabled using the method of invention.~~

Finally, we already have some commercial interest in the method despite limited advertisement. Peregrine Corporation, a leader in ultra fast silicon electronic circuit manufacturing based on silicon-on-sapphire technology, is interested in signing a non-disclosure agreement to investigate integration of their silicon technology and nitride semiconductor based emitters and detectors to explore "on chip" optical interconnects. A feasibility study is just underway with Defense Advanced Research Project Agency funding.

E. Alternatives

The closest alternative to the method of subject is the approach outlined in the background section, epitaxial lateral overgrowth (ELO). As mentioned there, the high quality material exists in the laterally overgrown wings, which precludes its efficient use for vertical conduction devices.

F. Contributions by Inventors

a. Peckerar – derived basic device process flow
b. Henry – devised p-doping technique
c. Koleske – derived self-assembled crystallite growth process
d. Wickenden – derived nucleation layer optimization process

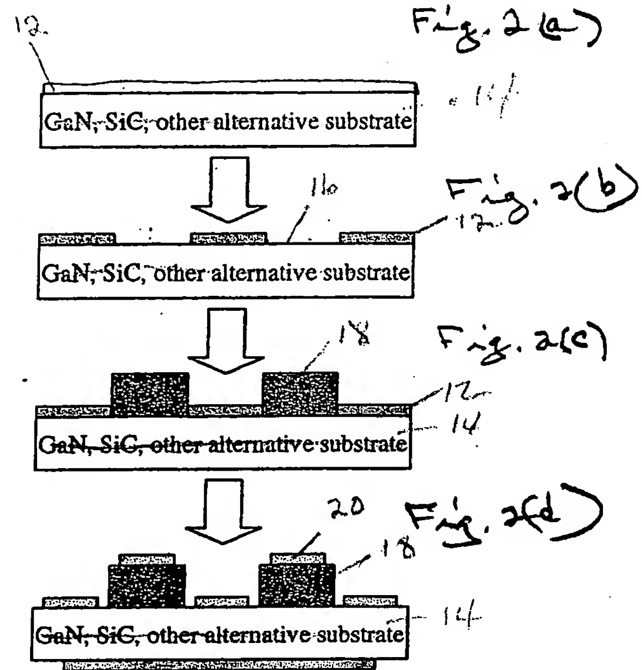


Fig. 2
~~**Figure 1. Schematic flow of patterned growth process.**~~

The substrate can have a variety of forms. We have performed our initial demonstrations using sapphire substrates that have had a thin film of n-type GaN deposited on them. It is reasonable to expect that the benefits demonstrated below can be magnified if applied to bare sapphire or silicon carbide substrates. It is also feasible to employ the technique on other technologically significant substrates such as silicon or gallium arsenide.

The mask material can be deposited in many ways. We have demonstrated successful growth of structures using atmospheric pressure oxides and sputtered oxides. The essential aspect is that the mask material layer be continuous and sufficiently dense so as not to allow nucleation through pinholes. Further the mask material can be pattered using substractive (etching) or liftoff approaches. We have demonstrated successful growth on samples patterned with either method. The essential aspect is that the openings be clean and the surfaces be "epi-ready".

We have grown only GaN in the mask openings, but it is fully expected that ternaries of AlGaN and InGaN as well as quarternaries of AlGaInN can be deposited using this approach. The patterned structures we've deposited have been successfully doped n-, or p-type as needed for device structures. Critical aspects are the percentage open area of the mask as well as the size of openings and the spacing between openings.

An example of the primary advantage of the technique is demonstrated in Figure 2. This transmission electron micrograph shows specifically the rapid reduction of extended defect density in the selectively grown material for an opening of 20 micrometers across. As can be seen in the figure, nearly an order of magnitude reduction in defect density is achieved within a few microns of selective growth. We believe that the reduction in stress of the selectively grown material due to the presence of free surfaces at the

sidewalls contributes significantly to the reduction in extended defects. Further, we anticipate that smaller openings will accentuate this stress reduction and result in even more rapid extended defect reductions that will allow defect-free device active regions to be grown.

~~Dislocation density reduction from 4x10⁹/cm² to 6x10⁸/cm²~~

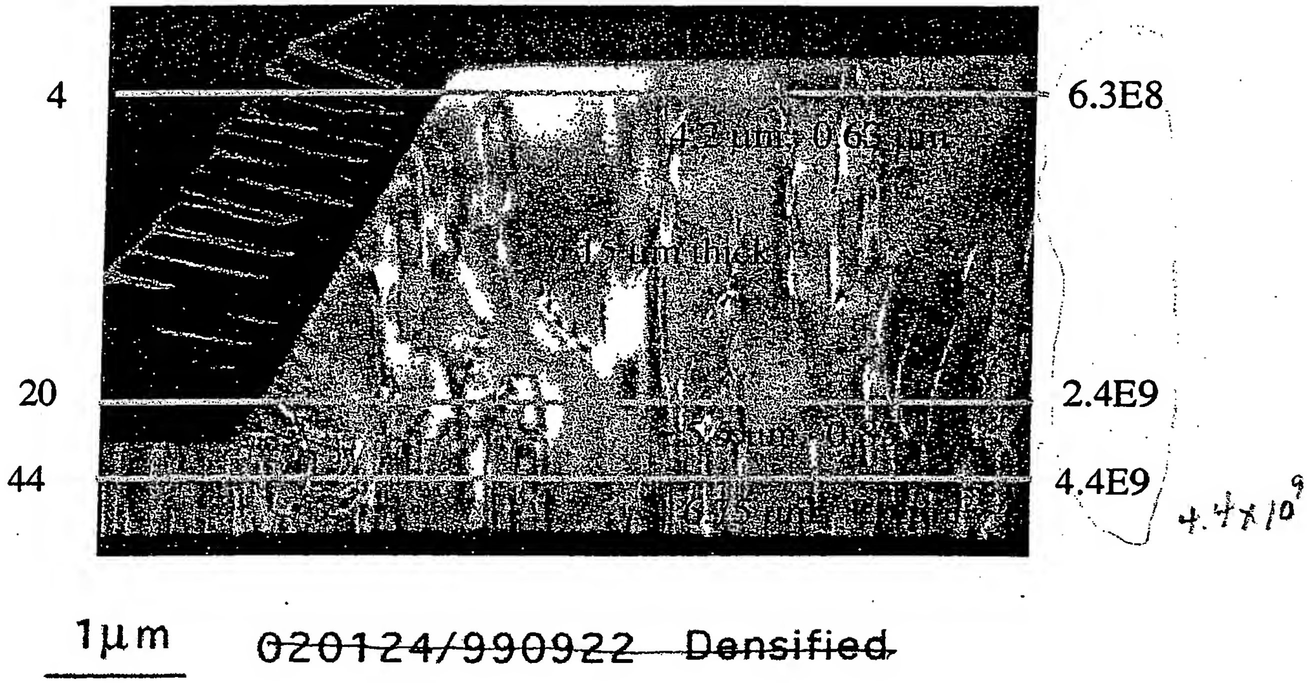
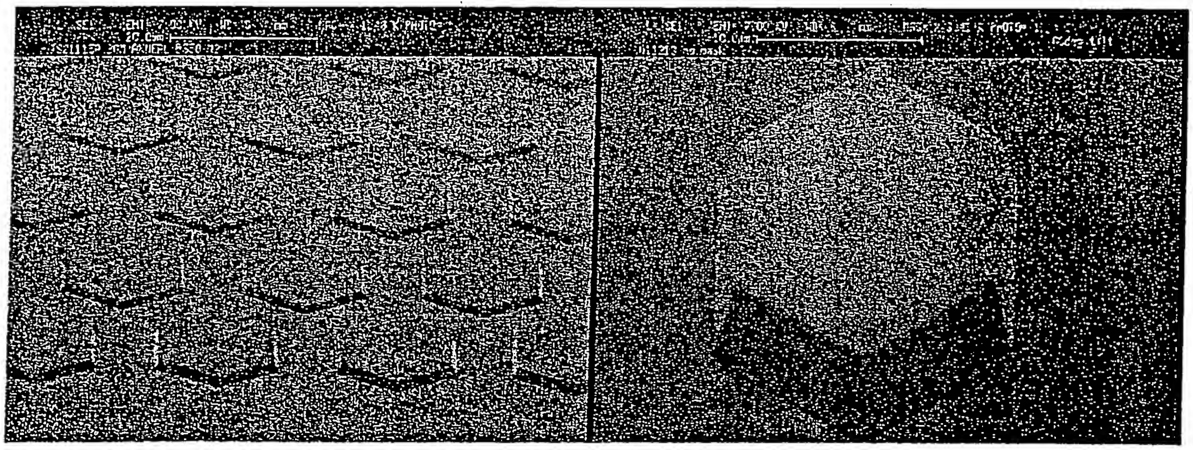


Fig. 3

~~Figure 2. Transmission electron micrograph showing the reduction of dislocation density in the patterned growth region.~~

Another significant advantage of the technique is that the free surfaces of the selectively grown material are atomically flat. Such surfaces can be seen in the scanning electron micrographs of Figure 3. This should enhance the effectiveness of passivation coatings (better bonding arrangements) and is critical to the creation of high efficiency light emitting and laser diodes with edge emission.



~~1450x~~ ~~3400x~~

Fig. 4

~~**Figure 3. Scanning electron micrographs of patterned growth mesas. Note smooth sidewall facets of the mesa.**~~

We have also measured the current-voltage characteristics of pn junction diodes created using this method. An exemplary characteristic is shown in Figure 4. Note that the reverse bias leakage current (likely to be most affected by the presence of extended defects) is extremely low. Also note that the device shown was unpassivated such that surface leakage currents could contribute to the measurement.

how determined

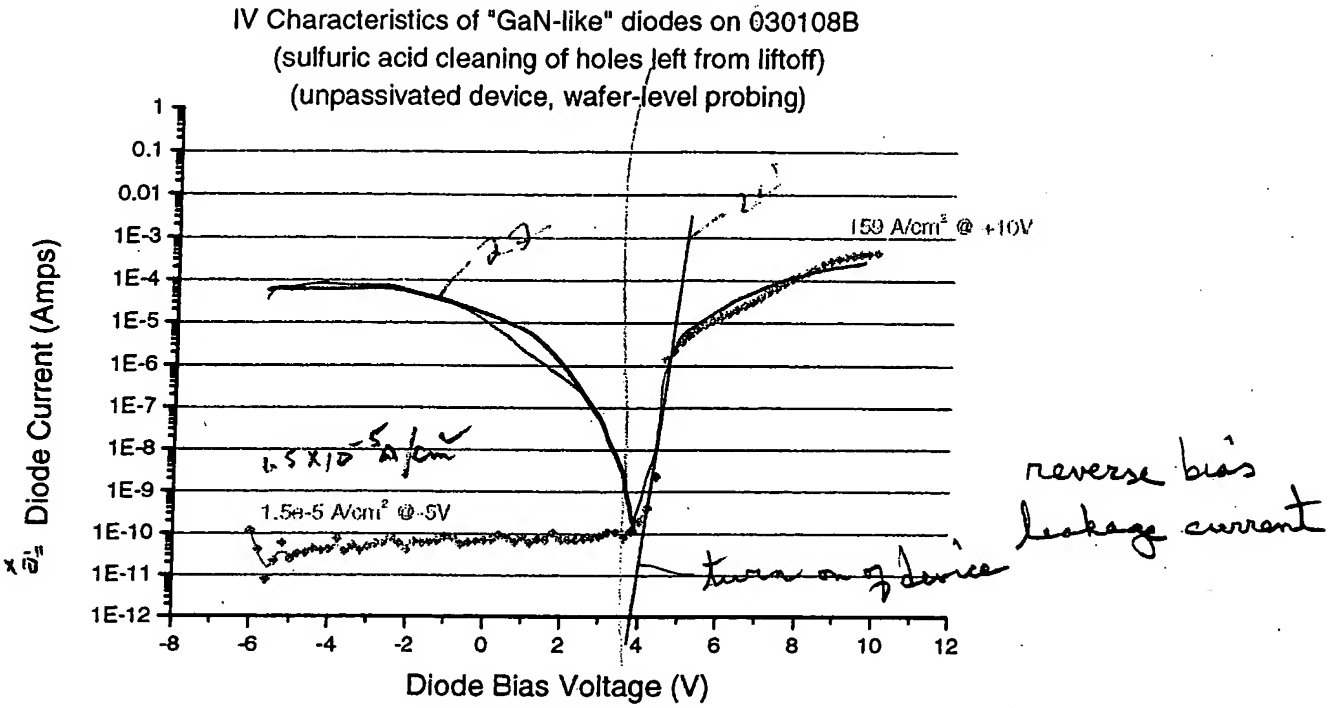


Fig. 5

~~Figure 4. Current-voltage characteristic of GaN diode grown using patterned growth method.~~

D. Advantages and New Features

This method of depositing wide bandgap semiconductor nitrides should improve the quality of device layers on traditional substrates such as sapphire and silicon carbide. That advantage should be extended to other technologically significant substrates such as silicon and gallium arsendie because the strain due to lattice mismatch should still be reduced and, therefore, the quality of the material improved. Such an advantage can enable new integrated technologies. Another advantage of the method with regard to heterogeneous integration with device technologies based on other materials is that the process steps used in patterned growth are compatible with traditional semiconductor processing.

The reduction in strain achieved by the method results in reduced extended defect densities. These extended defects have a deleterious effect on doping efficiency and the thickness of layers that can be achieved before cracking. By rapidly reducing the number of extended defects it is anticipated that films will have a lower background doping concentration that should lead to more controllable and efficient doping. The thicker films will also permit large blocking layers required for high voltage power devices. explain